QUARKONIUM PRODUCTION AND POLARISATION WITH EARLY DATA AT ATLAS

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One of the first physics results to come out of ATLAS will be an analysis of J/ψ and Υ production at 14 TeV. I give an overview of the motivation for looking at the theoretical model underlying quarkonium production, ATLAS expected performance and rates for quarkonium reconstruction and ability to separate out various proposed production models with a view to improving our understanding of QCD.

1. Introduction and motivation

When switched on, the LHC will produce charm and beauty quarks in abundance even in low luminosity runs during the first few years of running and the production rate of quarkonia such as J/ψ and Υ, important for many physics studies, will also be large. The reasonable branching fraction of both the J/ψ and the Υ into charged lepton pairs allows for easy separation of these events from the huge hadronic background at the LHC.

Their importance for ATLAS is threefold: first, being narrow resonances, they can be used as tools for alignment and calibration of the trigger, tracking and muon systems. Secondly, understanding the details of the prompt onia production is a challenging task and a good testbed for various QCD calculations, spanning both perturbative and non-perturbative regimes. Last, but not the least, heavy quarkonia are among the decay products of heavier states, serving as good signatures in searches for rare decays and CP-violating processes which form the backbone of the long-term ATLAS B-Physics programme. These processes have prompt quarkonia as a background and, as such, a good description of the underlying quarkonium production process is crucial to the success of these studies.

*on behalf of the Atlas Collaboration.

2. Overview and current status

The Colour Singlet Model (CSM) [1] of quarkonium production enjoyed some success before CDF measured an excess of direct J/ψ production [2] more than an order of magnitude greater than predicted, with incorrect p_T dependence. The Colour Octet Mechanism (COM) [3] was proposed as a solution to this problem, suggesting that the heavy quark pairs could evolve into a quarkonium state with particular quantum numbers through radiation of soft gluons during hadronisation.

Despite the successes of COM [4], recent measurements at CDF [5] and DØ [6] show disagreement with COM predictions on polarisation. The polarisation of the quarkonium state can be determined by measuring the parameter $\alpha = (\sigma_T - 2\sigma_L)/(\sigma_T + 2\sigma_L)$, which may vary between +1 for 100% transversely polarised, to −1 for 100% longitudinally polarised production. This can be achieved by measuring the distribution of θ^*, the angle between the positive muon from the quarkonium decay (in the quarkonium rest frame) and the quarkonium direction in the lab frame. Various production models [3,7] predict different p_T dependencies of the quarkonium polarisation, so this quantity serves as an important measurement for discriminating these models.

It is interesting to note that the results from DØ and CDF disagree both with each other, and various theoretical predictions. Both experiments suffer from low acceptance in the discriminating high $|\cos\theta^*|$ region. ATLAS is expected to be capable of detailed checks of the predictions of these and other models in a wider range of $|\cos\theta^*|$, p_T and η.

3. Observation of quarkonium in ATLAS

Two main trigger scenarios are considered here for the study of prompt quarkonia. The first is a di-muon trigger which requires two identified muons, both with a 4 GeV p_T threshold and within a pseudorapidity of $|\eta| < 2.4$. The di-muon sample considered here has offline cuts of 6 and 4 GeV p_T applied to the two identified muons. The second scenario is a single muon trigger in which only one identified muon is required, with a $p_T > 10$ GeVand $|\eta| < 2.4$, which is combined offline with Inner Detector tracks reconstructed down to a minimum p_T of 0.5 GeV.

The mass resolutions at ATLAS are expected to be approximately 54 MeV(J/ψ) and 170 MeV(Υ). The main expected sources of background are indirect J/ψ from B-decays, the continuum of muons from heavy flavour decays, Drell-Yan and decays in flight of $K^\pm$ and $\pi^\pm$. Figure 1 shows the

reconstructed invariant mass distribution in the J/ψ and Υ region for the di-muon dataset. For an integrated luminosity of 10 pb^{-1} we expect signal yields to be approximately 150,000 J/ψ and 25,000 Υ . The background under the J/ψ and Υ peaks is suppressed with vertexing and impact parameter cuts on the muons and a pseudo-proper time cut on the reconstructed quarkonium candidate.

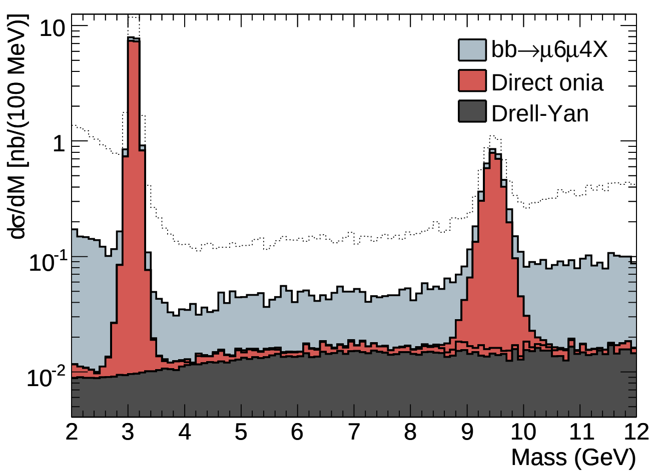

Figure 1. Sources of low invariant mass di-muons, after background suppression cuts. The light dotted line shows the background level before vertexing and proper-time cuts.

4. Polarisation and cross-section measurement

It can be seen that $\cos\theta^* \simeq 0$ corresponds to events where both muons have roughly equal transverse momenta, while in order to have $\cos\theta^*$ close to ±1 (the crucial area) one muon's p_T needs to be very high with the other p_T very low. In the case of a di-muon trigger, both muons from the J/ψ and Υ decays are forced to have relatively large transverse momenta. Whilst this condition allows both muons to be identified, it also severely restricts acceptance in the polarisation angle $\cos\theta^*$, meaning that for a given p_T a significant fraction of the total cross-section is lost.

With the single muon trigger one removes the constraint on the second muon. Now one has a high p_T muon which triggered the event

and one reconstructed track down to a p_T threshold around 0.5 GeV. Thus, the onium events with a single muon trigger typically have high values of $|\cos\theta^*|$, complementing the di-muon sample (see Figure 2, which shows the acceptance for both triggers). Combined carefully together the single and di-muon samples provide excellent coverage across almost the entire range of $\cos\theta^*$ over the same onia p_T range. The measured distributions from the combined data sample are corrected for acceptance and efficiencies to recover the true underlying distribution.

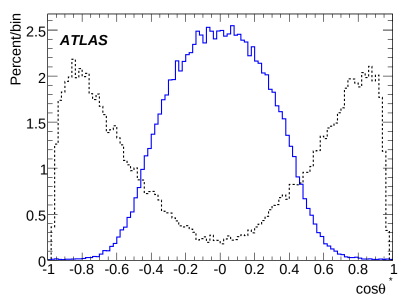

Figure 2. Acceptance of $\cos\theta^*$ in di-muon (solid line) and single muon (dashed line) datasets for J/ψ. The *true* angular distribution in both cases is flat.

Three MC datasets were produced, with fully transverse/ longitudinal polarisation and one with zero polarisation, to test the ability of ATLAS in these limit cases. The resultant distributions for the $\alpha_{gen} = \pm 1$ datasets are shown in Figure 3 and are detailed for all three in Table 1, along with the corrected cross-section in that p_T bin. The errors shown include statistical errors on the data, as well as the systematic effects of uncertainties on the acceptances and efficiencies.

Table 1. J/ψ and Υ polarisation and cross-sections measured in slices of p_T, for 10 pb^{-1}.

Sample	p_T, GeV	$9-12$	$12-13$	$13-15$	$15-17$	$17-21$	>21
J/ψ	α	0.156	-0.006	0.004	-0.003	-0.039	0.019
		±0.166	±0.032	±0.029	±0.037	±0.038	±0.057
$\alpha_{\rm gen}=0$	σ, nb	87.45	9.85	11.02	5.29	4.15	2.52
		±4.35	±0.09	±0.09	±0.05	±0.04	±0.04
J/ψ	α	1.268	0.998	1.008	0.9964	0.9320	1.0217
		±0.290	±0.049	±0.044	±0.054	±0.056	±0.088
$\alpha_{\rm gen}=+1$	σ, nb	117.96	13.14	14.71	7.06	5.52	3.36
		±6.51	±0.12	±0.12	±0.07	±0.05	±0.05
J/ψ	α	-0.978	-1.003	-1.000	-1.001	-1.007	-0.996
		±0.027	±0.010	±0.010	±0.013	±0.014	±0.018
$\alpha_{\rm gen}=-1$	σ, nb	56.74	6.58	7.34	3.53	2.78	1.68
		±2.58	±0.06	±0.06	±0.04	±0.03	±0.02
Υ	α	-0.42	-0.38	-0.20	0.08	-0.15	0.47
		±0.17	±0.22	±0.20	±0.22	±0.18	±0.22
$\alpha_{\rm gen}=0$	σ, nb	2.523	0.444	0.584	0.330	0.329	0.284
		±0.127	±0.027	±0.029	±0.016	±0.015	±0.012

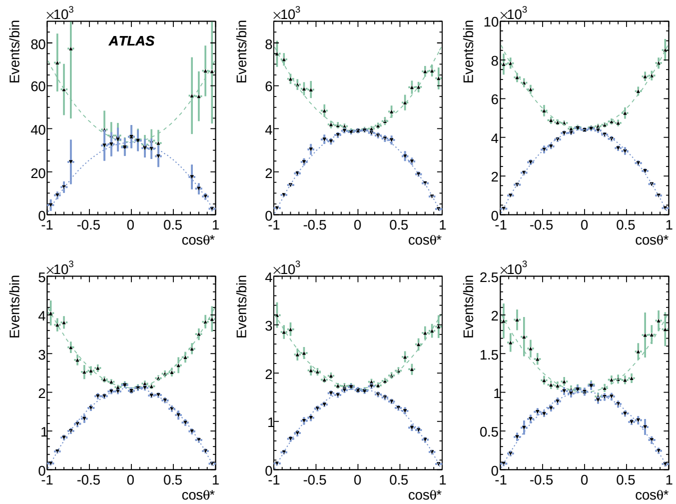

Figure 3. Acceptance and efficiency corrected J/ψ polarisation angle distribution ($\alpha_{gen} = \pm 1$) for increasing p_T slices (see Table 1). Statistics for $\int \mathcal{L} = 10$ pb^{-1}.

With an integrated luminosity of just 10 pb^{-1}, due to the high rate ATLAS aims to measure the polarisation of prompt vector quarkonium states to far higher transverse momenta than previous experiments with extended coverage in $\cos\theta^*$, which will allow for improved fidelity of efficiency measurements and thus reduced systematics. The precision of the J/ψ polarisation measurement can reach $0.02 - 0.06$ (dependent on the level of polarisation itself).

References

1. See e.g. V. G. Kartvelishvili *et al. Sov. J. Nucl. Phys.* **28** (1978) 280; M. Gluck *et al. Phys. Rev. D* **17** (1978) 2324; V. G. Kartvelishvili, A. K. Likhoded, *Sov. J. Nucl. Phys.* **39** (1984) 298; E. L. Berger and D. L. Jones, *Phys. Rev. D* **23** (1981) 1521; B. Humpert, *Phys. Lett. B* **184** (1987) 105.
2. F. Abe *et al.* [CDF Collaboration], *Phys. Rev. Lett.* **69** (1992) 3704.
3. G. T. Bodwin, E. Braaten and G. P. Lepage, *Phys. Rev. D* **51** (1995) 1125 E. Braaten and S. Fleming, *Phys. Rev. Lett.* **74** (1995) 3327
4. M. Kramer, Prog. Part. Nucl. Phys. **47** (2001) 141 [arXiv:hep-ph/0106120].
5. A. Abulencia *et al.* [CDF Collaboration], *Phys. Rev. Lett.* **99** (2007) 132001.
6. V. M. Abazov *et al.* [D0 Collaboration], DØ Note 5089-conf.
7. S. P. Baranov, *Phys. Rev. D* **66** (2002) 114003; J. P. Lansberg, J. R. Cudell and Yu. L. Kalinovsky, *Phys. Lett. B* **633** (2006) 301 [arXiv:hep-ph/0507060].
8. ATLAS Collaboration, to be published as part of CERN Yellow Report "Expected Performance of the ATLAS experiment".